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L.G. Hill

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INTRODUCTION

For over 35 years the copper cylinder test has been the primary source of high explosive (HE) product equation-of-state (EOS) data. Traditional instrumentation comprised electrical pins to measure detonation velocity, and a streak camera to measure liner motion. The advent of velocity interferometry in the early 1970's allowed the two-dimensional "slab" variant to be instrumented (1,2). The Sandwich test is a carefully engineered slab test that accommodates initial temperatures between -55 C and 75 C.*

GEOMETRY: SLAB VS. CYLINDER

Slab and cylindrical geometries both have inherent pros and cons. Which is most desirable will depend on the situation. The primary advantage of slab geometry is better high-pressure resolution. This is because the flow expands in only one lateral direction, so that pressure falls off slower with axial distance. Moreover the liner can be made thinner, and of a higher impedance material, to give a finer shock ring-up structure.

In cylindrical geometry the liner stretches and thins, so that only a very ductile material like pure annealed copper can expand sufficiently without tearing. In slab geometry the liner only bends. This allows its material to be chosen by other criteria; it also allows the liner to be thinner to start with. This aside there is the issue of fabrication, and the difficulty in accurately machining very thin-walled soft copper tubes.

The second advantage of slab geometry is that it is conducive to designs that accommodate a wide range of initial charge temperatures. Differential thermal expansion between HE and liner make this prospect very difficult for cylindrical geometry— particularly in the cold case, as the cylinder test is quite intolerant of gaps.

An optimal Sandwich test with thin liners requires a machined HE sample to maintain a precise assembly. This precludes other physical HE forms such as liquid, putty, or powder. Of course these could be accommodated by a design with thicker, rigid walls, but that would largely defeat the advantages of slab geometry. Such materials are better suited for the cylinder test.

Another practical limitation of the Sandwich test is that it must use a velocity interferometer, rather than a streak camera, to measure liner velocity. A cylinder test can use both instruments simultaneously. Velocity interferometers have a modest depth-of-field, which limits the test size to that comparable to a traditional 1-inch cylinder test. For insensitive HEs a larger test is desirable to minimize reaction zone effects. A streak camera can measure arbitrarily large cylinders simply by adjusting the magnification (e.g., 3).

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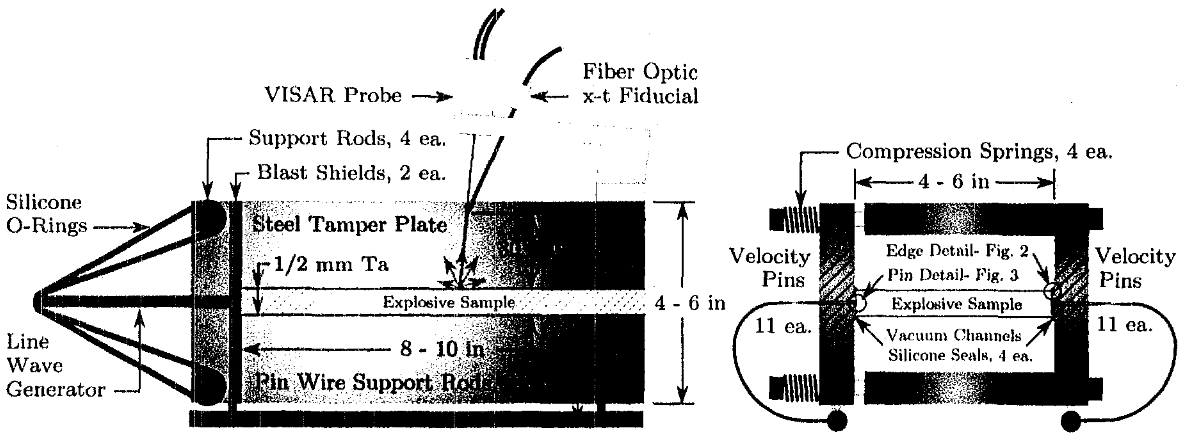

FIGURE 1. Schematic diagram of the Sandwich test, with nominal dimensions (see detail, Figs. 2 & 3).

SIZE & MATERIALS

The design goal is to develop a slab alternative to the standard 1-inch cylinder test. To do so we must first set the corresponding dimension— the slab thickness. Detonation Shock Dynamics theory (4) shows that detonation curvature effects are nominally equivalent when the cylinder radius is equal to the slab thickness, in this case 1/2 inch. (This is why the failure *thickness* of an HE is very close to half its failure *diameter.*)

Next we must choose a liner material and thickness. The detonation transmits a shock into the liner that reverberates downstream through its thickness δ_l, the wall velocity jumping in increments of the axial round trip distance Δ. Hence, Δ represents the effective spatial resolution. In the Mach angle approximation Δ is

$$\Delta = 2\,\delta_l\sqrt{\left(\frac{D_0}{c_l}\right)^2 - 1}; \quad \delta_l = \frac{m_{al}}{\rho_l}, \qquad (1)$$

where D_0 is detonation velocity, c is sound speed, m_a is mass/area, ρ is density, and l denotes the liner. For EOS analysis it is desirable that the *Gurney approximation* be satisfied. This requires m_{al} to be $\geq$1/3 of the HE mass/area (5). Having fixed m_{al}, Δ is minimal if the remaining expression is minimal. This favors stiff, high density metals such as Mo, Ta, and W. Other material factors are acoustic impedance (higher values *tend* to provide better confinement and D_0 closer to D_{cj}) and toughness (which resists tearing and spall). Overall, Tantalum seems the best choice.

Additional factors affect optimal liner thickness. Δ should exceed the reaction zone length, otherwise the detonation loses confinement and deviates more from D_{cj}. The liner must be thick enough not to break during observation, and its RMS thickness variation should be small compared to the mean (which favors thicker sheets). Finally, the present design needs a sheet thickness that is flexible, but not prone to creasing.

The other dimensions scale with the maximum measured wall expansion, E. Existing tests used a commercial (VALYN^{TM} FOP-1000-60mm) VISAR probe, with $30 \leq E \leq 40$ mm. Edge effects should be minimized by heavy tamping plates with half-width E or greater.

The distance from probe beam to downstream charge end is such that the detonation breaks out when the liner has traveled a distance E. Consequently late liner motion is not affected by the termination. The same run is allowed between the line wave initiator and the probe beam, allowing the liner to reach its steady trajectory prior to observation. Computations have confirmed this length to be sufficient (6).

The slab width is governed by two issues. First, the product wake at the edges must not block the probe beam during the measurement. Second, the test should be wide enough that, with sides heavily tamped, the detonation wave and following flow are two-dimensional near the centerline. These criteria require a slab half-width of order E. Figure 1 shows a schematic diagram with nominal dimensions.

DESIGN & INSTRUMENTATION

This section discusses critical implementation issues, starting with the liner. The 20-mil thick Ta sheet is manufactured by Rembar Corp. It is commercially pure and annealed, with mean grain size ≈25 μm. As-received sheets are precisely cut to length and width, and paired as closely as possible according to mean thickness.

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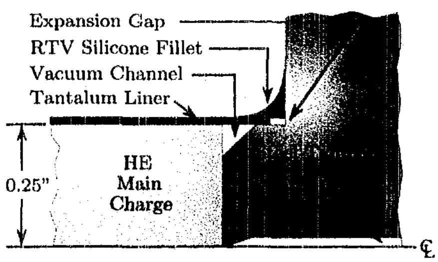
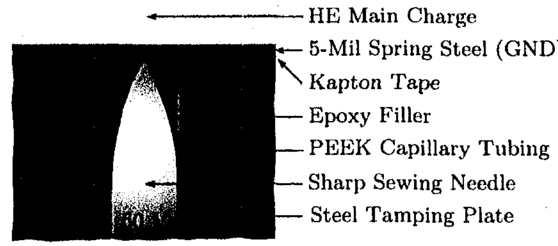


FIGURE 2. Edge detail (cf. Fig. 1).

The velocity pins shown in Figs. 1 & 2 are detailed in Fig. 3. Sharp pins are epoxied inside PEEK capillary tubing, which is glued into holes in the tampers. The installed point locations are measured by optical comparator. The pins are capped by a spring steel shim strip insulated by Kapton tape, recessed to be flush with the tamper ridge and tight against the HE. The detonation drives the shim through the Kapton into the pin, completing an electrical circuit. In hot or cold shots the pins move with the tamper, so their ambient spacing may be adjusted by the tamper thermal expansion. The standard error in velocity so-obtained is within 5 m/s.



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The Sandwich test is challenging for VISAR because the plate travels through a large distance and angle. The difficulty lies in both absolute light level, and the limited dynamic range of fast scopes. Happily, one may compensate by sanding the target region of the liner (using a diamond file for Ta) in the lateral direction; this forms a grating that fans scattered light in a plane that remains coincident with the probe as the liner turns (7). One may also place the probe at an initial stand-off distance and angle ϕ that generates the most uniform light return. For a steady flow with specified D_0 and ϕ, an exact transformation then yields the liner trajectory.

Fiber optic fiducial pins (see Fig. 1) precisely positioned along the probe beam path generate a light flash, and hence an x-t point, when struck by the liner. These give an independent measure of the VISAR fringe constant, allowing correction of a small 2D aberration that arises due to the finite probe beam size. A small error from the increased refractive index behind the air shock is essentially eliminated by firing in Helium.

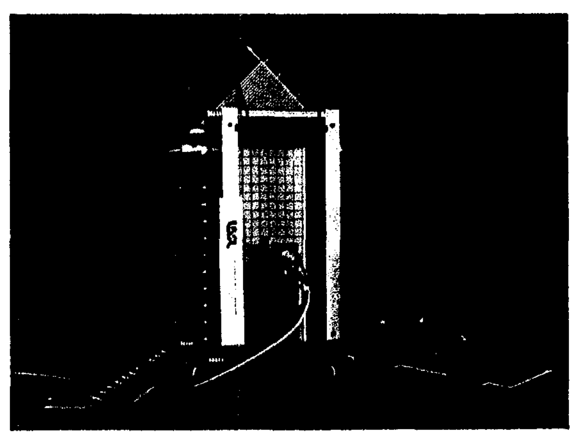


FIGURE 4. Sandwich test photograph (Shot# 8-666).

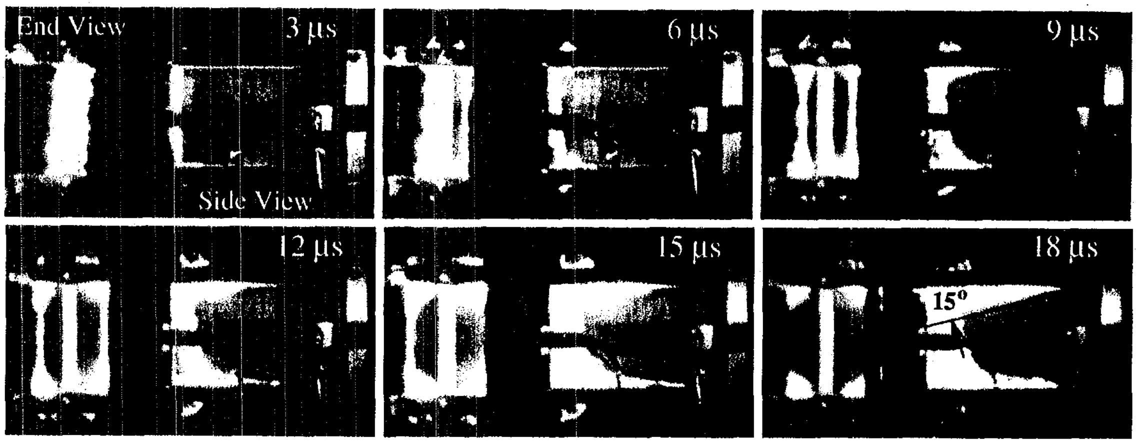
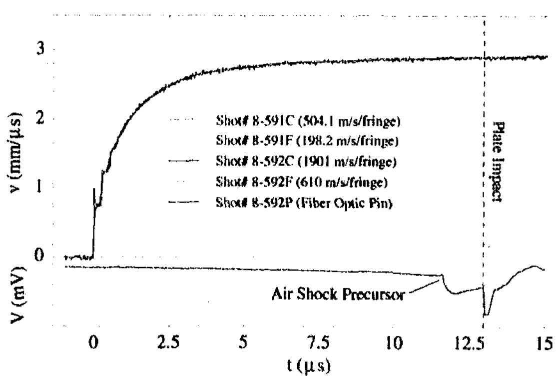


FIGURE 5. Framing camera pictures of a detonating Sandwich test (Shot# 8-592). Liner grid is 1 cm square.

SAMPLE RESULTS

Figure 5 shows electronic framing camera pictures of a PBX 9501 Sandwich test detonating in air. The left side of each frame is the end view, with detonation approaching the viewer. The right side is the side view (via mirror), with detonation travelling to the right. The liner jump-off is visualized by light from the air shock, and shows that the detonation is flat. The product wake develops at about a 15^o angle, leaving a clear view for the VISAR probe beam. Both liners hold together during the measurement.

Figure 6 shows a composite of six VISAR records for four shots (two of which had dual VISARs with differing sensitivities). The repeatability is essentially within the signal noise. The bottom trace is a fiber optic fiducial pin signal from one of the tests. This can be interpreted to with a time resolution less than 10 nsec.



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ONGOING DEVELOPMENT

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ACKNOWLEDGEMENTS

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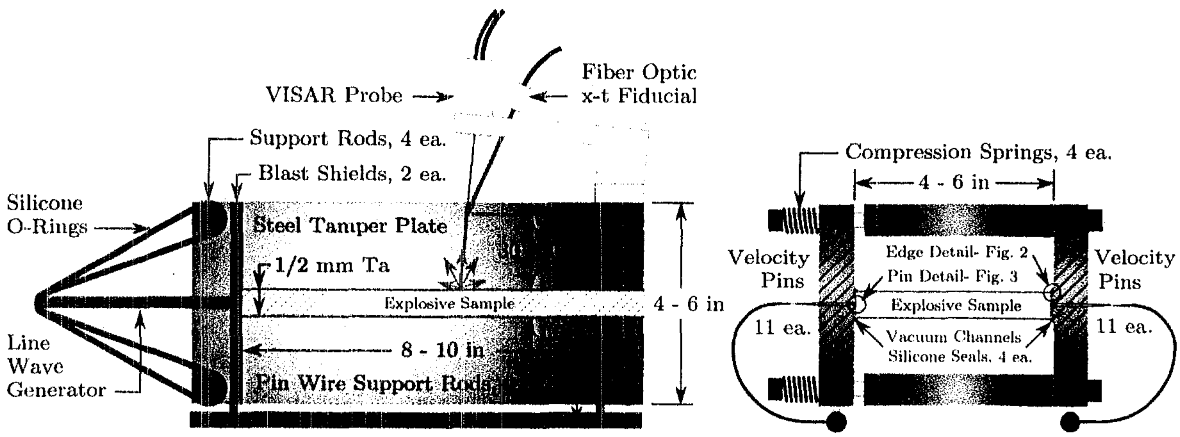

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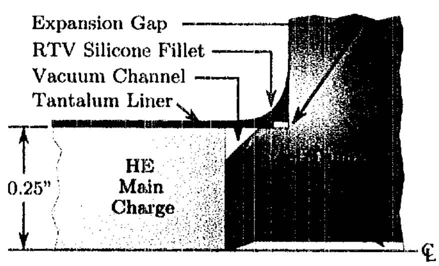

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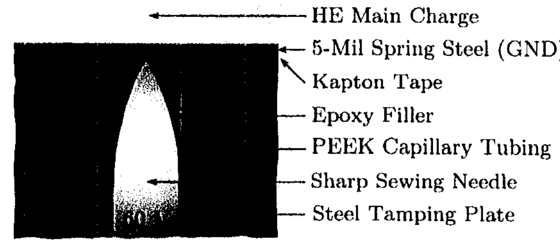

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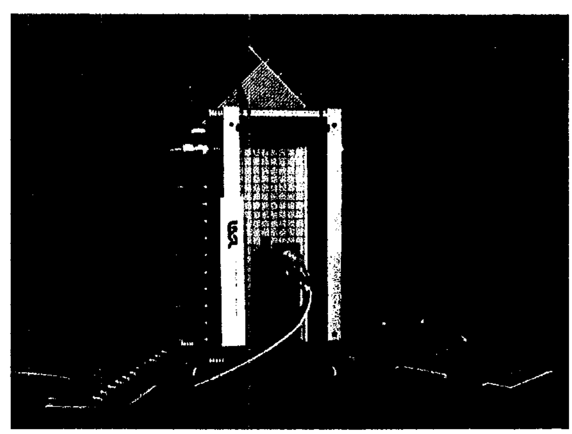

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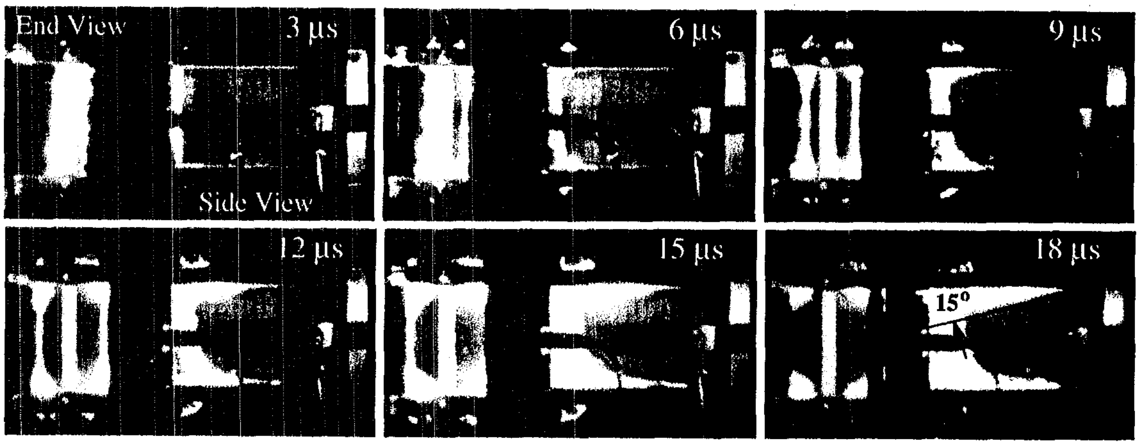

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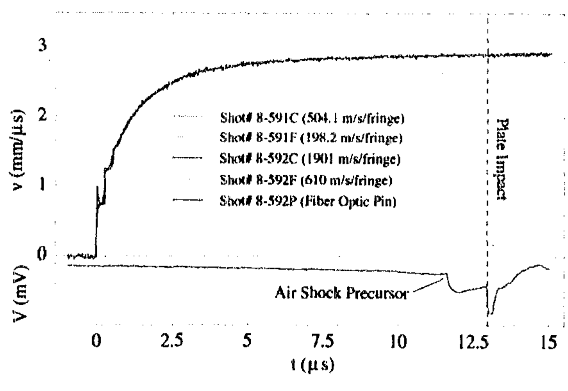

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